National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

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Deep Space Atomic Clock Technology Demonstration Mission
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National Aeronautics and Space Administration
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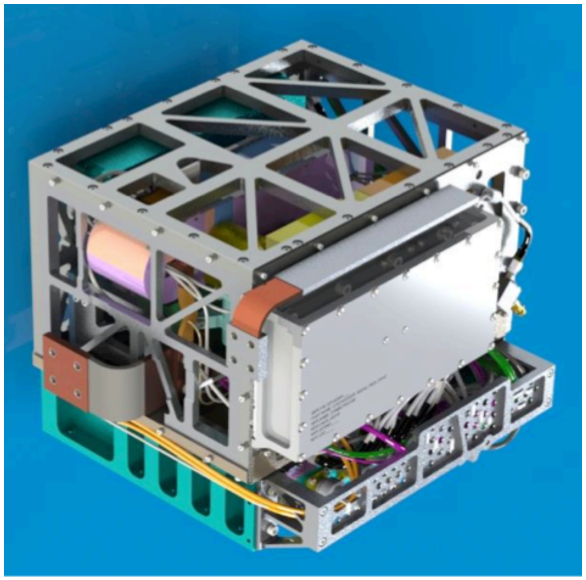
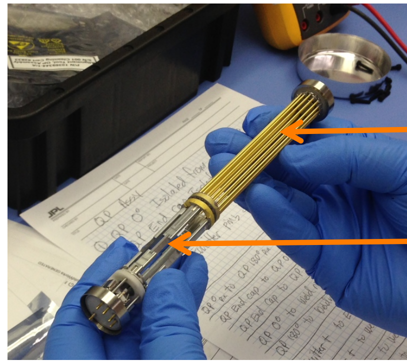
Deep Space Atomic Clock Project

NASA's DSAC Technology Demonstration Mission

DSAC Demonstration Unit (CAD)

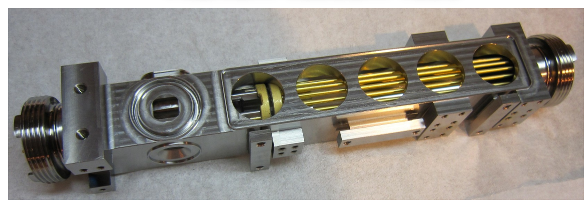




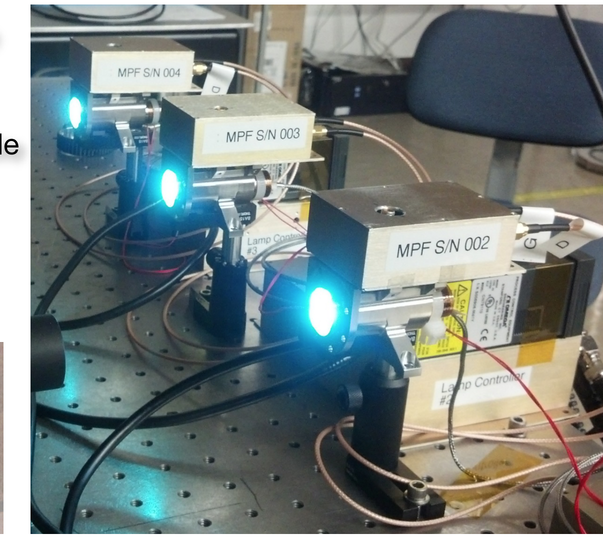
Multi-pole Trap

Quadrupole Trap

Titanium Vacuum Tube



Mercury UV Lamp Testing



Develop advanced prototype ('Demo Unit') mercury-ion atomic clock for navigation/science in deep space and Earth

- Perform a year-long demonstration in space beginning in 2016 – advances the technology to TRL 7
- Focus on maturing the new technology – ion trap and optical systems – other system components (i.e. payload controllers, USO, GPS) size, weight, power (SWaP) dependent on resources/schedule
- Identify pathways to 'spin' the design of a future operational unit (TRL 7 → 9) to be smaller, more power efficient

For More Information, Contact: Todd.A.Ely@jpl.nasa.gov, Website: http://www.nasa.gov/mission_pages/tdm/clock/

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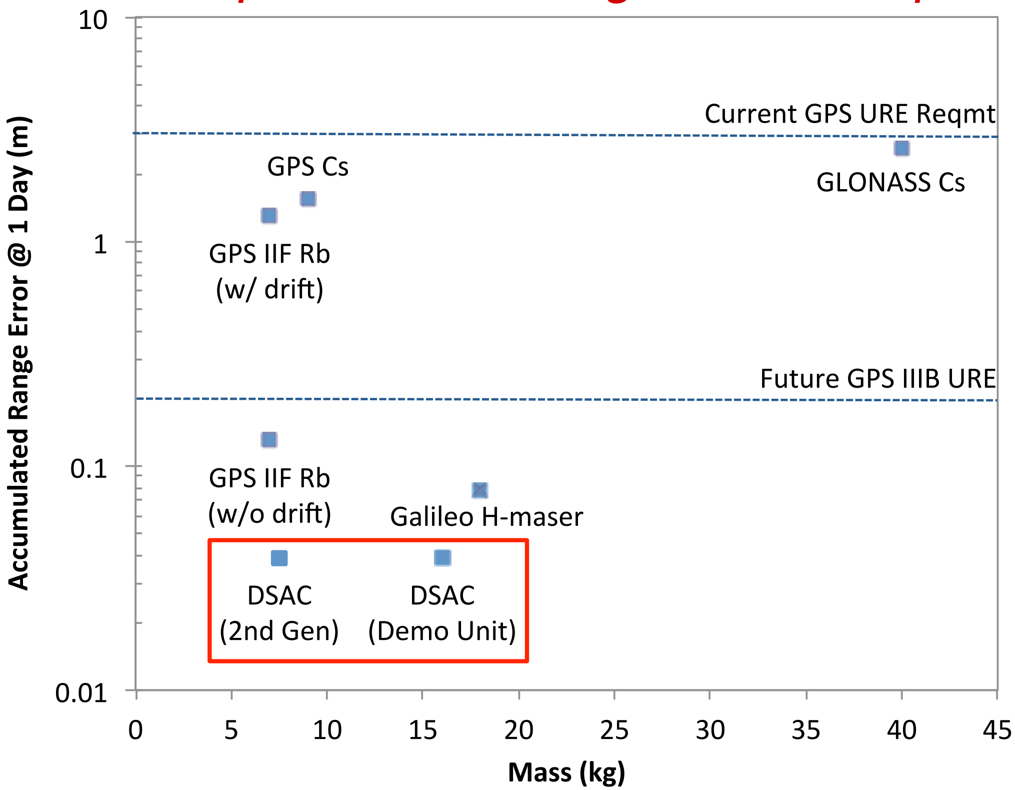
DSAC Compared to Existing GNSS Frequency Standards



AFS	Average Power
DSAC Demo Unit (1st Generation)	< 50 W
DSAC Future Unit (2nd Generation)	< 30 W
GPS IIF Rb (5th Generation)	< 40 W
Galileo H-Maser (2nd Generation)	< 60 W

- Required AD (including drift) of < 3e-15 at one-day (current estimate at 1.5e-15) outperforms existing GNSS frequency standards
- Demo Unit SWaP is competitive – next version would focus on simplifying electronics to significantly reduce SWaP
- Easily satisfies future GPS IIIB URE that includes both clock and ephemeris errors

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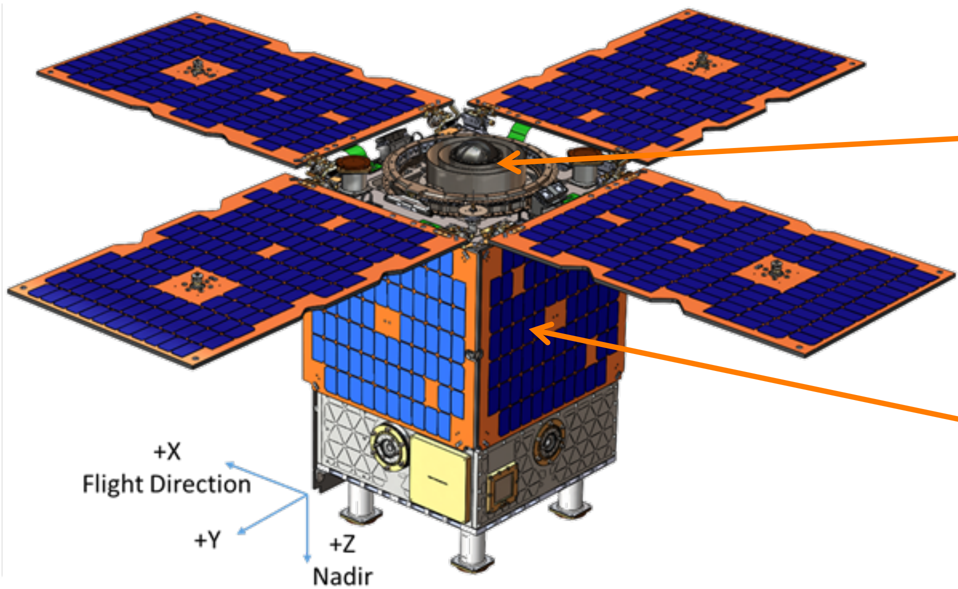
DSAC Demonstration Payload and Hosting



DSAC Payload Elements

- Zenith-oriented choke ring GPS antenna
- USO (FEI)
- DSAC Demo Unit
- TriG GPS receiver (Moog Broad Reach)

- DSAC flight experiment of the Demo Unit as a hosted payload on Surrey Satellite Technology US's Orbital Test Bed II (OTB II) spacecraft
  - OTB II is a 180 kg ESPA-compatible spacecraft – fixed arrays, no active maneuvering, nadir fixed attitude maintained/controlled via reaction wheels/magnetorquers.
  - OTB II hosting other payloads including several Air Force experiments
- Launched as part of USAF STP II (a Space X Falcon 9 Heavy) currently scheduled for May 2016

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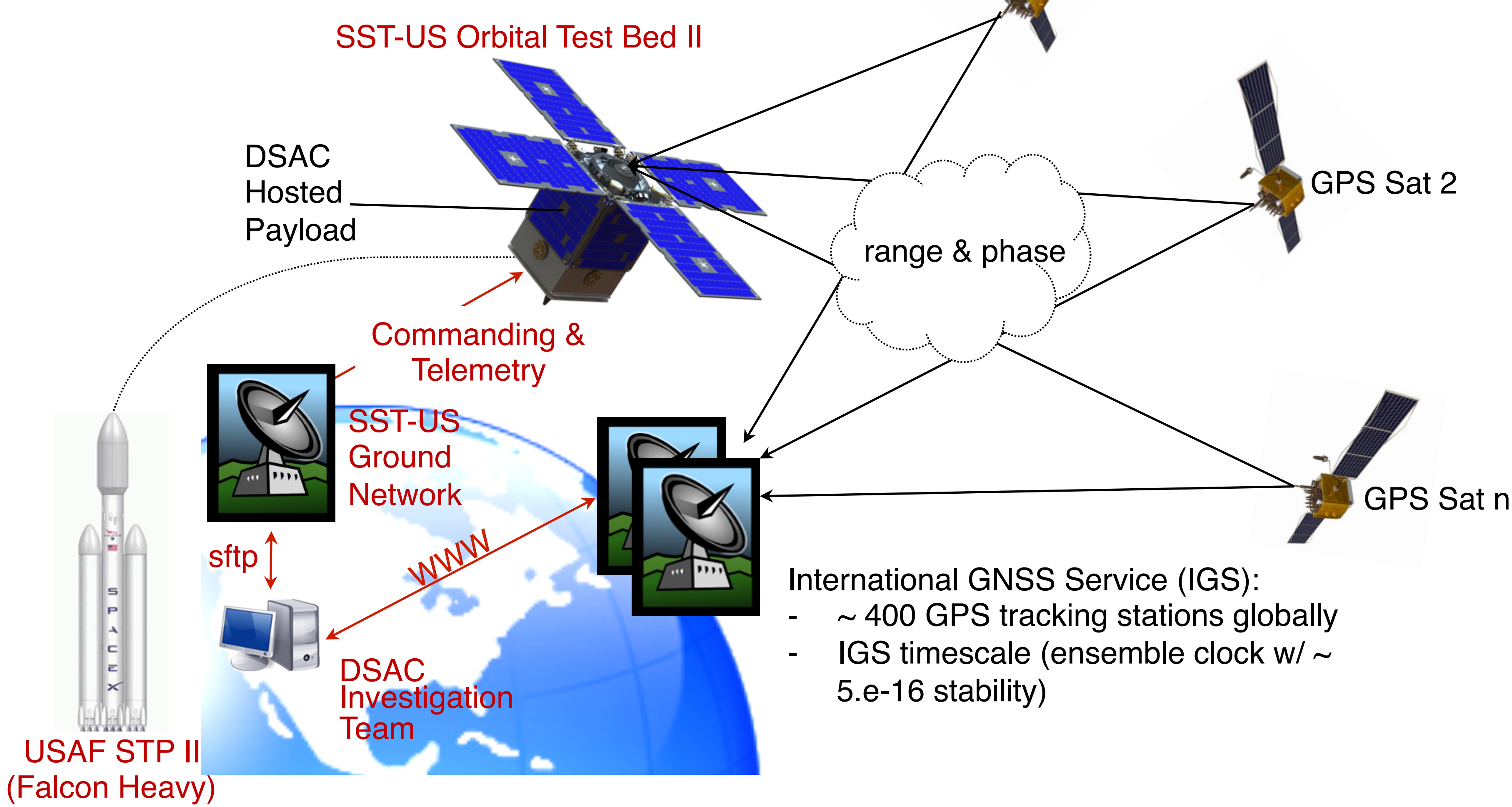
DSAC Mission Architecture

Launch May 2016 with one-year demonstration



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Schedule

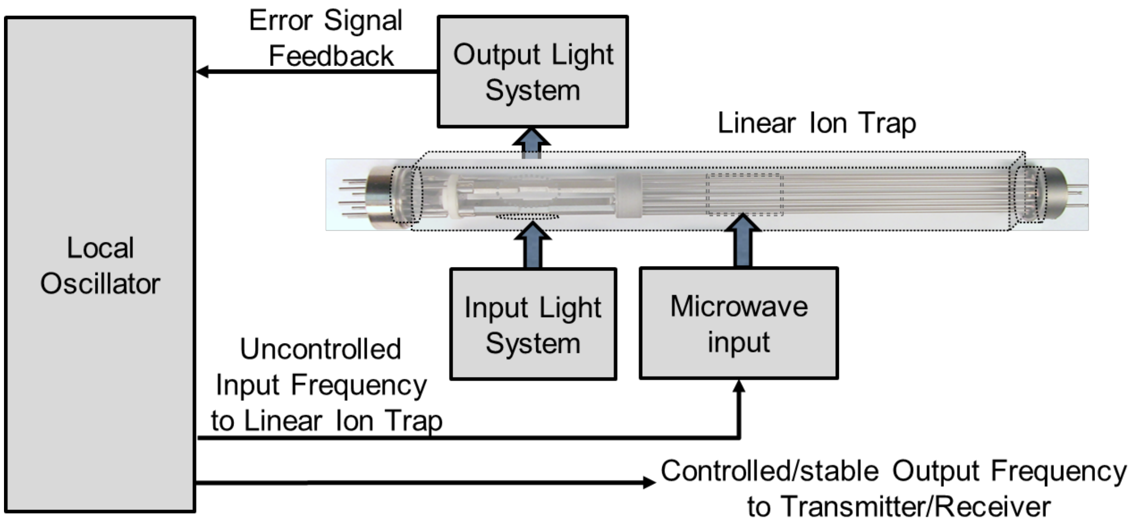
• Mission Definition & System Reqmts Review	February 2012 ✔
• Preliminary Design Review	May 2013 ✔
• NASA Commitment Review (KDP-C)	November 2013 ✔
• Clock Critical Design Review	July 2014
• Mission CDR & System Integration Review	September 2014
• Pre-Ship Review	March 2015
• Flight Readiness Review	February 2016
• Launch & Mission Operations	May 2016 + 1 Year

DSAC, GPS, and Other DOD Applications

- Future GPS III URE goals require performance gains in a number of areas including clocks
  - DSAC performance significantly shortens one of the ‘tent poles’ contributing to URE
- DSAC can contribute to other AF programs and government agencies with atomic clock needs
  - DSAC performance (considering no intrinsic drift) well suited for autonomous operations needed by future secure command and control satellite systems currently in study
- Development of an operational mercury atomic frequency standard (MAFS) based on DSAC technology realizable in a near-term time horizon
  - Alternate technologies (cold cesium atom and optical Rb) are at lower readiness levels with TRL 7 not achievable for another 5 – 10 years
  - Current DSAC a point of departure for MAFS with flight experiment results in 2016 feeding into MAFS design and development
  - Low level effort starting as soon as FY ’15 would focus on simplifying tube manufacturing and increasing lamp lifetime using known measures with success leading towards a fully committed project developing an operational MAFS
  - Frist operational demonstration of MAFS on the 4th slot (with monitoring capability) of a future GPS satellite or alternate AF platform (such as NavSat) provides pathway for new technology adoption in operational PNT systems

Backup

DSAC Technology and Operation



Ion Clock Operation

- Short term (1 – 10 sec) stability depends on the Local Oscillator (DSAC selected USO 2e-13 at 1 second)
- Longer term stability (> 10 sec) determined by the "atomic resonator" (Ion Trap & Light System)

Key Features for Reliable, Long-Life Use in Space

- No lasers, cryogenics, microwave cavity, light shift, consumables
- Low sensitivity to changing temperatures (7e-16/C @ 1-day), magnetics (3e-15/G @1-day), voltages (3e-16/V @ 1-day)
- Radiation tolerant at levels similar to GPS Rb Clocks

Ion Clock Technology Highlights

- State selection of 10^6-10^7 $^{199}Hg^+$ electric-field contained (no wall collisions) ions via optical pumping from $^{202}Hg^+$
- High Q microwave line allows precision measurement of clock transition at 40,507,347,996.8 Hz with

$$SNR \times Q = \frac{3e-13}{\sqrt{\tau}}$$

- Ion shuttling from quadrupole to multipole trap to best isolate from disturbances
- 1-2 UV photons per second scattered
- Ions are in an uncooled Neon buffer-gas

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DSAC's Crosscutting Customer Base – Infusion Targets

Near Space Navigation/Timing	Deep Space Navigation	Science	Deep Space Timing	Autonomy
USAF – SMC/GPS USAF – MILSATCOM NRO	**NASA IND/DSN NASA SMD/PSD**	**NASA SMD/PSD**	**NASA IND/DSN NASA SMD/PSD**	**NASA SMD/PSD**
• Improve GPS clock performance • Diversifies clock industrial base - enhancing national security • Provides needed time accuracy/ stability for next generation secure communications • Significant aid to users with compromised GPS visibility – need only 3 in-view to position	• Multiple Spacecraft Per Aperture at Mars - doubles useful tracking • Full use of Ka-band tracking – OD uncertainty at Mars < 1 m (10 x improvement) • Outer planets users gain significant tracking efficiency – 15% at Jupiter 25% at Saturn	• Enhance gravity science at Mars, GRACE-level determination of long term gravity with one satellite, at Europa, flyby gravity objectives met robustly • Enhance planetary occultation science with 10 x better data	• Significantly reduce spacecraft timekeeping overhead • Improve reliability of critical time-dependent autonomous spacecraft functions • Reduce risks to long-term spacecraft hibernation	• Enables autonomous radio navigation (robotic and crewed) • Enhances EDL and precision landing • Key component to autonomous aerobraking • Coupled with OpNav, enhances primitive body exploration

Cross-cutting Customer Base Reduces the Risk of Infusion

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